Collaborative Research with W. McCann and C. Mendoza: Improving the Seismic Hazard Model for Puerto Rico through Seismic Tomography and a Reliable Microearthquake Catalog With Recalculated Magnitudes and Calibrated Hypocentral Error Estimates

Annual Project Summary:

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Nontechnical Summary

Data from a local seismic network were used to estimate the three-dimensional seismic velocity structure for Puerto Rico. We identified a northerly dipping region of higher than normal seismic velocities extending from the near the surface off the south coast to 60 kilometers depth. This feature lies just beneath a similarly dipping zone of seismic activity. Together these results confirm the existence of the Muertos Megathrust, a major earthquake hazard. Other results include identification of a region of high velocities in the region near the Utuado Batholith, and a region of low velocities near the north coast tertiary basin.

Investigations Undertaken

The Puerto Rico Seismic Network (PRSN), a local network of about 20 seismic stations, has monitored earthquake activity in the Puerto Rico-Virgin Islands region since 1975. More than 18,000 earthquakes have been located by the PRSN to date, with most of these in the 1.0-3.0 magnitude range. The history of the network has been such that catalogs of events near Puerto Rico and the Virgin Islands contain events located by two separate networks, using at least two different computer programs, with at least two different crustal models. In addition, event magnitudes have been calculated based on at least two different scales of uncertain equivalence.

Work conducted under the current project is aimed at improving the utility of the PRSN earthquake catalog in hazard models through the development of a 1-D Vp/Vs model using *Velest*, a local 3-D seismic velocity model using the program *Simul2000* developed by Thurber (1993) and development of a catalog of jointly located local earthquakes with moment calibrated magnitudes based on the new moment magnitude scale developed by Motazedian and Atkinson (2004). Principal tasks undertaken to date are 1) the preparation of a new local earthquake catalog with relocated events and recomputed magnitudes based on the *Velest* 1-D P-wave and a new Vp/Vs velocity model, 2) the assessment of location accuracy using the *Velest* crustal model, and 3) the derivation of a 3-D velocity model for the Puerto Rico-Virgin Islands region.

Results

Hypocentral Catalog- The 1-D P-wave and Vp/Vs velocity models given in Table 1 (below) have been used to relocate all earthquakes in the Puerto Rico catalog (1975-2001). The use of this improved 1-D velocity model in the earthquake location process provides most accurate estimate of the hypocenters in the region to date. In addition, new relations between moment magnitude and observed coda times and P-wave amplitudes are being developed by relating the moment magnitudes calculated by Motazedian and Atkinson (2004) and available coda and amplitude information for the Puerto Rico region. Recomputed hypocenters and magnitudes will be incorporated into a unified earthquake catalog that will allow a more complete assessment of the earthquake hazard and a better characterization of active faults.

Evaluation of Earthquake Location Accuracy-The improved 1-D seismic velocity model derived using Velest presumably provides more accurate estimates of the hypocenters in the region. The location accuracy of any given event at any given time, however, depends not only on the accuracy of the velocity model but also on the errors in the phase-arrival measurements and the geometric distribution of the stations that record the event. The computer program LOK (Zivcic and Ravnik, 2000) is being used to evaluate the degree to which the hypocenters are accurately recomputed throughout the region. The program follows the method described by Peters and Crosson (1972) to construct hypocenter error ellipsoids for a uniform distribution of grid points within a prescribed region encompassing a particular distribution of recording stations. Even if the velocity model and phase-arrival times are exactly known, there is an inherent inaccuracy in the hypocentral location that is due to the particular distribution of the recording sites (Zivcik and Ravnik, 2000). The LOK program uses the fact that the errors of the travel time solution depend on the partial derivatives of the travel time function with respect to the hypocenter location and the earthquake origin time. Errors in the phase-arrival times and uncertainties in the velocity model are explicitly specified in the program to derive location errors for each point along the regional grid. The program thus identifies contributions to the hypocentral error that are due both to the geometric distribution of the seismic stations and to the combined uncertainty in the velocity model and phase-arrival times.

Mendoza and Huerfano (2005) recently used the program LOK to estimate epicentral errors for earthquakes occurring at different depths in the Puerto Rico-Virgin Islands region as a function of velocity uncertainty in the assumed crustal structure. The Velest results, however, allow us to identify the absolute location errors for the artificial sources. Thus, by computing epicentral-location error maps for the known station distributions similar to those presented by Mendoza and Huerfano (2005), we can estimate the probable uncertainty in the Velest 1-D velocity model and additionally infer the likely location errors in other parts of the Puerto Rico-Virgin Islands region and assess the accuracy of the catalog locations obtained using the 1-D velocity model. Such a realistic estimate of the location errors is necessary for the accurate identification of seismic source zones and potential seismogenic faults, which would directly impact the estimation of seismic hazard in the region. Identifying the general uncertainty in the Velest 1-D velocity model is also useful for evaluating the expected location accuracy for any distribution of seismograph stations; for example, for earthquakes recorded by the present-day configuration of seismograph stations.

New Velocity models

1-D Velest Vp/Vs model

In a recent investigation funded by NEHRP (Project#04HQGR0015), McCann used the 18,000 events located since 1975 by the Puerto Rico-Virgin Islands regional network with the program *Velest* to develop regional 1-D velocity models for the Puerto Rico and Virgin Islands regions using a jointly located dataset. Table 1 shows the P-wave velocity models obtained by McCann for the two regions using the program *Velest,* as well as the new Vp/Vs model for the Puerto Rico Region. The results of the 1-D modeling efforts make it clear that there are significant variations in both crustal thickness and velocity in the area near Puerto Rico and the Virgin Islands.

Table 1. 1-D *Velest* derived Vp, Vp/Vs velocity models for Puerto Rico and Virgin Islands

Puerto Rico			Depth to top of Layer (km)		Virgin Islands	Depth to Top of Layer (km)
Vp (km/sec)	Vs	Vp/Vs			Vp (km/sec)	
6.45	3.62	1.78	-3		6.04	-3
7.13	4.16	1.71	17		6.43	9
8.01	4.61	1.74	31		7.50	24

3-D Velocity Model

The *Velest* velocity model from Table 1 was additionally used to initiate the tomographic inversion process for the Puerto Rico region using the program *Simul2000* (Thurber, 1993). Figure 1 shows the area of study and the earthquake data used to derive the 3-D velocity structure. The depth interval considered for the study region is 100 km. Seismograph stations and the number of P-wave arrivals used in the inversion are given in Table 2.

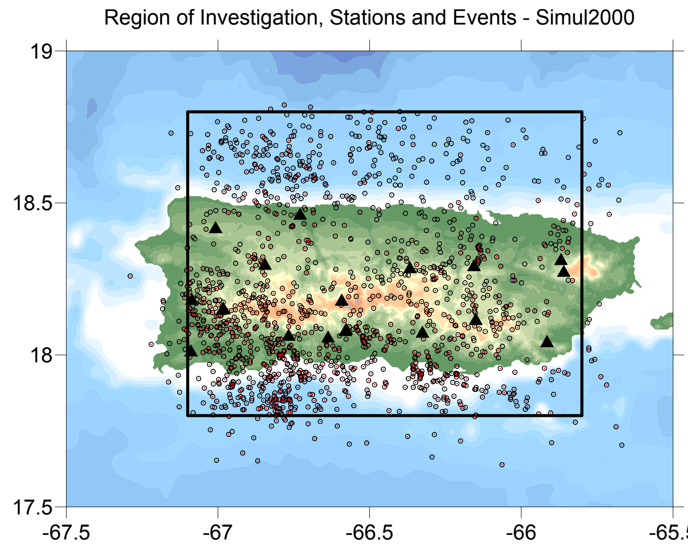

Figure 1. Location of 1540 locally recorded earthquakes with 8859 arrival times (red, green and blue circles) and 21 stations (black triangles) used to derive a 3-D velocity model using the program *Simul2000.* Box indicates region of investigation as determined by initial event locations. Event symbol depth classes: Red 0-30 km; Green 30 –75 km; Blue 75-150 km

The tomographic analysis was conducted in several steps. First, a mesh of coarse 3-D elements was defined across the length, width, and depth of the study region, and the inversion was run using the *Velest* 1-D model as the starting model. This served to adjust the earthquake locations and 1-D velocity model to a 3-D structure. The inversion was then repeated iteratively using recomputed hypocenters until the best fit was obtained. In subsequent steps, the number of 3-D elements was incremented by progressively decreasing the size of each volume. In our analysis of the Puerto Rico earthquake data, the size of the 3-D elements were decreased from coarse (40 km node spacing) to medium (20 km node spacing) to fine (10 km) to very-fine (7 X 5 X 5 km node spacing).

The most important result of this portion of the project is the verification of the existence of Caribbean plate, presumably subducted along the Muertos Trough, beneath the southern of Puerto Rico. In Figure 2 the Caribbean slab is seen as an East-West laterally extensive region of higher than normal velocities (as much as +3%) dipping to the north at mid-and lower crustal levels and shallow levels in the upper mantle. This feature extends to about 60 km depth where velocities return to normal. At the upper surface of this region of lower than normal velocities lies a similarly dipping seismic zone, presumably reflecting the interface between the upper and lower plates. The presence of this lithospheric slab has clear implications for seismic hazard in the Puerto Rico region.

Some other features are seen in the results of the 3-D velocity inversion, namely 2 first-order velocity anomalies near the surface, each of which correlates with known geologic features. Figure 3 shows three horizontal slices through the Puerto Rico region at depths of –1, 4 and 9 kilometers. The most prominent features are the region of low velocities near the central north coast of the island and a region of higher than normal velocities just to its southwest. As there is a geographical overlap between these anomalies and at least portions of large geologic features, we tentatively correlate the region of low velocity with the north coast tertiary basin (Larue et al., 1998), and the region of high velocity with the Utudao batholith (Jolley et al., 1998).

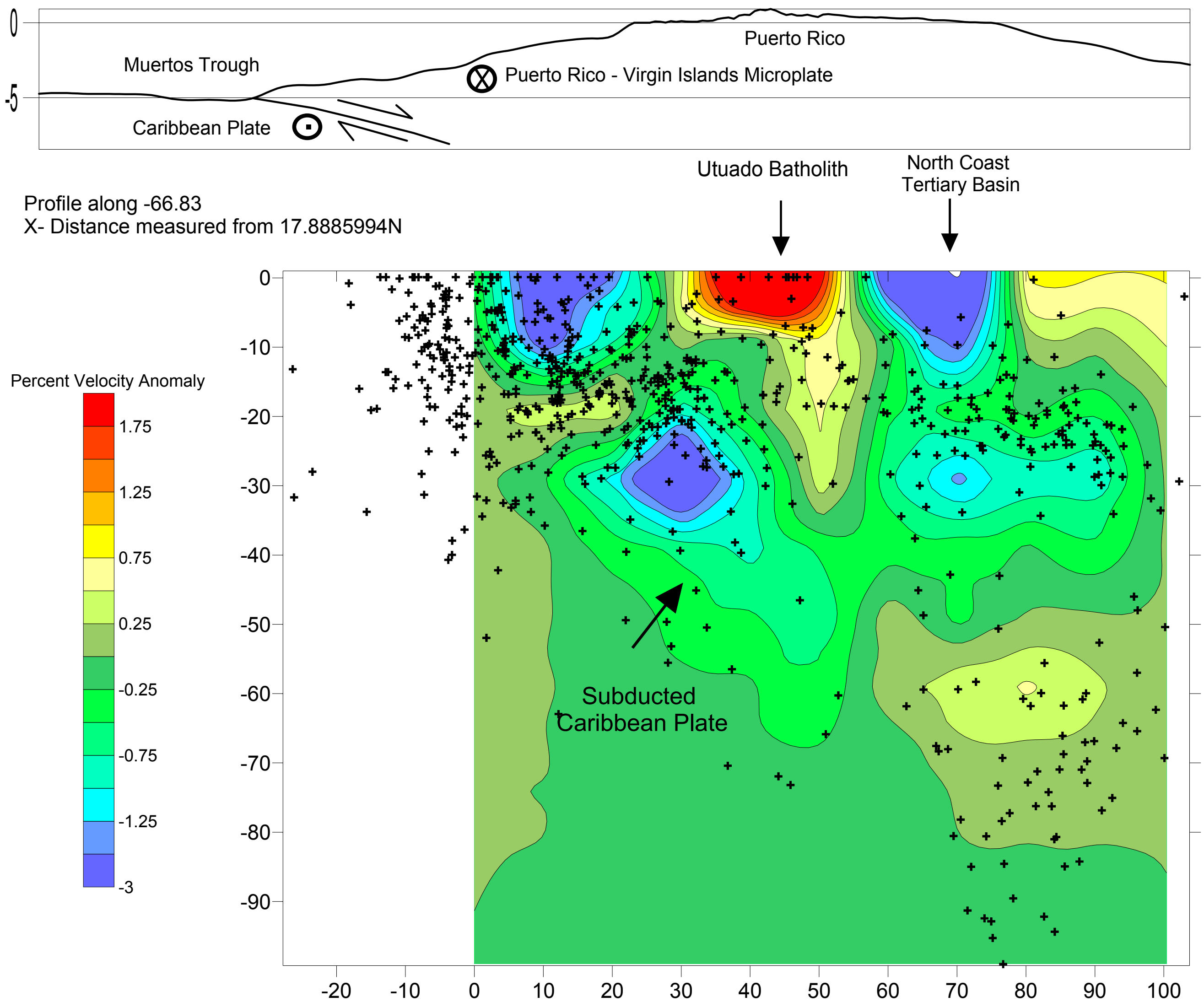

Figure 2. Upper panel: Regional relief (bathymetry and topography), location of plate boundaries (with motions dervied from GPS) are shown for reference. Lower Panel: Percent Vp velocity variation from the standard model along a north –south striking vertical slice at 66.83ºW. Also shown are earthquakes within 20 km of the profile center. The northerly dipping region of low velocity anomalies beneath S. Puerto Rico confirms the existence of subducted Caribbean slab beneath the island. Surficial velocity anomalies of the Utuado Batholith? and the North Coast tertiary Basin shown.

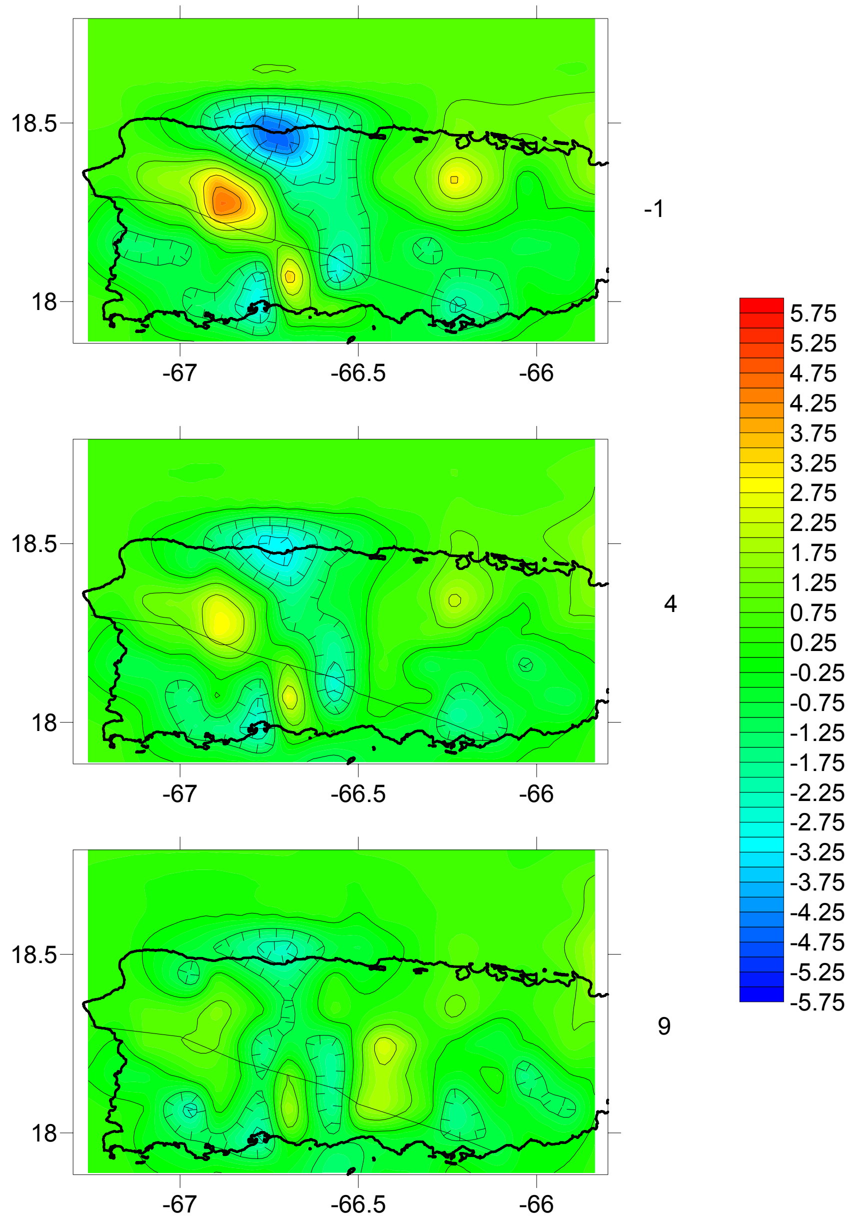

Figure 3. Horizontal slices through the simul2000 derived velocity model for Puerto Rico. Percent velocity anomaly from the standard model is given on the scale at the right. Warmer colors indicate higher velocities, cooler colors, lower velocities. Approximate trace of Great southern Puerto Rico Fault zones is shown diagonally crossing the island from the west coast of the southeastern part of the island. These slices show regional and local variations in velocity at crustal depths across the region. Two first order regions of P-wave velocity anomalies are seen. Along the northern coast to the west of the island's center is a region of lower than standard velocities that extends to at least 9 km depth. The location of this velocity low coincides with the location of the north coast tertiary basin. To the south and west lies a region of higher than normal velocities. This feature extends to at least 4 km depth and is spatially coincident with the Utuado batholith, of Cretaceous age.

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